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Declaration

I, Michihiko Matsuba, President of Fukuyama Sangyo Honyaku Center, Ltd., of 16-3, 2-chome, Nogami-cho, Fukuyama, Japan, do solemnly and sincerely declare that I understand well both the Japanese and English languages and that the attached document in English is a full and faithful translation, of the copy of Japanese Patent Application No. 2000-312110 filed on October 12, 2000.

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[TITLE OF DOCUMENT] SPECIFICATION

[TITLE OF THE INVENTION] Objective lens for optical head and optical system of optical head

[WHAT IS CLAIMED IS;]

[Claim 1] An objective lens for an optical head that is a single lens for gathering a laser beam emitted from a light source on a recording surface of an optical disk through a protective layer, wherein either lens surface is partitioned into a center region including an optical axis and an edge region enclosing a perimeter of the center region; the center region being formed as a continuous surface without a level difference; the edge region having a diffraction lens structure that consists of a plurality of concentric annular bands, each having a slight level difference; and the diffraction lens structure functioning to compensate a change in light-gathering properties caused by a temperature change.

[Claim 2] The objective lens of Claim 1, wherein the lens surface is partitioned so that an area of the edge region is narrower than that of the center region.

[Claim 3] The objective lens for an optical head, wherein the diffraction lens structure has a spherical aberration property by which spherical aberration varies toward compensatory deficiency when a wavelength of incident light

shifts to a long wavelength side.

[Claim 4] An objective lens for an optical head that is a single lens for gathering a laser beam emitted from a light source on a recording surface of an optical disk through a protective layer, wherein either lens surface is partitioned into a center region including an optical axis and an edge region enclosing a perimeter of the center region, and wherein a diffraction lens structure that functions to compensate a change in light-gathering properties caused by a temperature change is formed only in the edge region, the diffraction lens structure consisting of a plurality of concentric annular bands each having a slight level difference.

[Claim 5] An optical system of an optical head including a light source that emits a laser beam and an objective lens by which the laser beam is gathered on a recording surface through a protective layer of an optical disk, wherein either lens surface of the objective lens is partitioned into a center region including an optical axis and an edge region enclosing a perimeter of the center region; the edge region having a diffraction lens structure that consists of a plurality of concentric annular bands, each having a slight level difference; and the diffraction lens structure functioning to compensate a change in light-gathering properties caused by a temperature

change.

[Claim 6] The optical system of an optical head of Claim 5, wherein the center region of the objective lens is formed as a continuous surface without a level difference.

[Claim 7] The optical system of an optical head of Claim 5 or Claim 6, wherein the light source selectively emits a first laser beam and a second laser beam whose wavelength is longer than that of the first laser beam; the second laser beam is caused to strike the objective lens as divergent light; the first laser beam is caused to strike the objective lens as parallel rays of light or as divergent light weaker than the second laser beam; and the objective lens gathers the first laser beam on a recording surface of a first optical disk through a protective layer thereof and gathers the second laser beam on a recording surface of a second optical disk whose protective layer is thicker than that of the first optical disk and whose recording density is lower than that of the first optical disk.

[DETAILED DESCRIPTION OF THE INVENTION]

[0001]

[Field of the art]

This invention relates to a high NA (numerical aperture) objective lens used for an optical head of an optical information recording/reproducing apparatus, such as a DVD (digital

versatile disk) apparatus or a MOD (magneto-optical disk) apparatus, and relates to an optical system of an optical head using this objective lens.

[0002]

[Prior Arts and Themes Thereof]

A double-aspherical lens made of resin is generally used for an optical head of an optical information recording/reproducing apparatus that is required to reduce its weight and its size. However, since the resinous lens undergoes a greater refractive index change or a greater geometric change because of a temperature change than a glass lens, a performance change caused by this change is liable to produce a difficult situation. For example, when the temperature rises, the refractive index of the resinous lens falls, and thereby spherical aberration varies toward compensatory excess, so that wave front aberration deteriorates. The rate of the refractive index change with respect to the temperature change of the resinous lens is substantially $-11\times10^{-5}/°C$.

[0003]

Table 1 shows variations of wave front aberration (rms value, unit: λ (wavelength)) caused when the temperature rises by 40 degrees, i.e., when the refractive index varies by -440×10^{-5} of a resinous lens whose focal distance is 3.0 mm and whose

wavelength in use is 650 nm where NA is shown as a parameter, and Fig. 16 is a graph thereof.

[0004]

[Table 1]

NA	Wave Front Aberration (rms, unit: λ)
0.00	0.000
0.10	0.000
0.20	0.001
0.30	0.003
0.40	0.007
0.50	0.018
0.60	0.043

[0005]

Generally, in an objective lens for a CD (compact disk) apparatus, NA is about 0.45, and the upper limit of a tolerance of wave front aberration is about 0.04λ. Therefore, regardless of a temperature change of about 90 degrees, the wave front aberration falls within the allowable range, and the deterioration of the wave front aberration caused by the temperature change is practically negligible.

[0006]

[Problem that the invention intends to solve]

However, in an objective lens for a DVD apparatus, NA is about 0.60, and, in an objective lens for an MOD apparatus,

NA is about 0.55, and the upper limit of a tolerance of wave front aberration is about 0.03λ. Therefore, the wave front aberration exceeds the upper limit of the tolerance when a temperature change of about 40 to 50 degrees occurs, and there is the possibility that trouble will arise when information is recorded and reproduced.

[0007]

The present invention has been made in consideration of the problem of the conventional technique mentioned above, and it is an object of the present invention to provide an objective lens for an optical head that is capable of controlling a change in wave front aberration caused by a temperature change so as to be slight and enlarging a usable temperature range when employed as a high NA objective lens for a DVD apparatus or for an MOD apparatus.

[0008]

[Means for solving the problem]

In order to achieve the object, an optical system of the optical head according to the present invention is characterized in that either of the lens surfaces of the objective lens is divided into a center region that includes an optical axis and an edge region that surrounds the center region, in which the center region is formed as a continuous surface without a level

difference, and a diffraction lens structure that consists of a plurality of concentric annular bands having slight level differences is formed in the edge region. The diffraction lens structure functions to compensate a change in light-gathering properties caused by a temperature change.

[0009]

The provision of the diffraction lens structure as mentioned above makes it possible to avoid the influence of the temperature change. Further, the diffraction lens structure for temperature compensation can control a change in light-gathering performance at such a level as to be practically negligible if it is provided only in the edge region. Preferably, the surface division is carried out so that the area of the edge region is smaller than that of the center region. If the area of the edge region is greater than that of the center region, the wavelength dependence of the spherical aberration increases, and therefore the performance deterioration resulting from individual differences of the oscillation wavelength of a semiconductor laser because of lot differences will cause problems.

[0010]

As mentioned above, the spherical aberration of a refractive lens varies toward compensatory excess because of a temperature

rise. On the other hand, a semiconductor laser generally used as a light source of the optical head has a property by which the oscillation wavelength shifts to the long wavelength side in accordance with the temperature rise. Therefore, if the diffraction lens structure is provided with a property by which the spherical aberration varies toward compensatory deficiency as a result of shifting the wavelength to the long wavelength side, a change in the spherical aberration of the refractive lens that leads to the compensatory excess because of the temperature rise can be offset by a change in the spherical aberration of the diffraction lens structure that leads to the compensatory deficiency resulting from the wavelength shift of the semiconductor laser to the long wavelength side because of the temperature rise.

[0011]

Further, the optical system of the optical head according to the present invention is characterized in that it includes a light source that emits a laser beam and an objective lens that gathers the laser beam upon a recording surface through a protective layer of an optical disk, and in that a diffraction lens structure for temperature compensation is formed in an edge region on a lens surface of the objective lens.

[0012]

Preferably, in a case in which the optical system of the optical head is compatibly used for optical disks, such as a CD and a DVD, different in standards, the light source selectively emits a first laser beam with a short wavelength and a second laser beam with a long wavelength, and the second laser beam is caused to enter the objective lens in the form of a divergent beam of light, whereas the first laser beam is caused to enter the objective lens in the form of parallel rays of light or a divergent beam of light weaker than the second laser beam. In this case, the objective lens gathers the first laser beam on the recording surface of a first optical disk (e.g., DVD) whose protective layer is thin and whose recording density is high, and gathers the second laser beam on the recording surface of a second optical disk (e.g., CD) whose protective layer is thick and whose recording density is low.

[0013]

When two kinds of optical disks different in recording density are used as mentioned above, the diffraction lens structure for temperature compensation formed in the edge region of the objective lens is optimized with respect to the first optical disk with a high recording density. Therefore, a high numerical aperture (NA) can be secured for the first laser beam used when the first optical disk is used, and aberration is generated

for the second laser beam used when the second optical disk is used, so that a spot having a suitable size for the second optical disk larger than that for the first optical disk can be formed as a result of substantially reducing the numerical aperture.

[0014]

[Embodiments of the invention]

A description will be hereinafter provided of embodiments of the optical system of the optical head according to the present invention. The whole structure of the optical system will be first described, and then embodiments of the objective lens will be described. The optical head in these embodiments is recordable/reproducible to/from an optical disk (hereinafter referred to as "first optical disk") having a relatively high recording density like a DVD.

[0015]

Fig. 1 is an explanatory drawing of the optical system of the optical head according to a first embodiment. This optical system is made up of a laser module 21, a collimating lens 24, and an objective lens 10. The laser module 21 is an element in which a semiconductor laser and a sensor are integrated with each other. The objective lens 10 is movable in the direction of its optical axis by means of a known focusing mechanism (not

shown), and, additionally, is movable in the radial direction of an optical disk by means of a tracking mechanism.

[0016]

In order to use the first optical disk D1, such as a DVD, having a high recording density and having a protective layer of 0.6 mm, a red light with wavelengths of 635 to 665 nm is needed to form a small beam spot. Therefore, the laser module 21 includes a semiconductor laser having an oscillation wavelength of 650 nm.

[0017]

The laser module 21 is located exactly at a front focus of the collimating lens 24 so that a first laser beam emitted from the collimating lens 24 strikes the objective lens 10 in the form of parallel rays of light, i.e., so that the object distance of the objective lens becomes infinite.

[0018]

The first laser beam with a wavelength of 650 nm that has been emitted from the semiconductor laser of the laser module 21 strikes the objective lens 10 in the form of parallel rays of light, the first laser beam is then condensed by the objective lens 10, and the first laser beam forms a beam spot on the recording surface of the first optical disk D1. Reflected light from the optical disk is received by a light-receiving element

provided in the laser module 21, and thereby a focusing error signal and a tracking error signal are detected, and, when reproduced, a reproducing signal of recorded information is detected.

[0019]

Next, the structure of the objective lens 10 will be described in detail with reference to Fig. 2. Fig. 2 is an explanatory drawing for explaining the objective lens 10 according to the embodiment, where (A) is a front view, (B) is a longitudinal sectional view, and (C) is a partially enlarged view of the longitudinal section.

[0020]

The objective lens 10 is a double-convex single lens made of resin that has two aspherical lens surfaces 11 and 12. As shown in (A) of Fig. 2, the first surface 11 of the objective lens 10 is divided into a center region that includes an optical axis and an edge region that encloses the perimeter of the center region. The center region RC and the edge region RE are divided so that an area ratio becomes smaller than 1:1, i.e., so that the edge region RE becomes narrower than the center region RC.

[0021]

In the edge region RE of the first surface 11, a concentric annular band-like diffraction lens structure that centers the

optical axis is formed as shown in (A) of Fig. 2. As shown in (C) of Fig. 2, the diffraction lens structure has a level difference in the direction of the optical axis at the boundary of each annular band like a Fresnel lens. The center region RC of the first surface 11 and the whole region of the second surface 12 are each a continuous surface without a diffraction lens structure.

[0022]

The diffraction lens structure formed in the edge region RE functions to compensate a change in light-gathering properties caused by a temperature change. The diffraction lens structure has spherical aberration properties by which spherical aberration varies toward compensatory deficiency when the wavelength of incident light shifts to the long wavelength side. The spherical aberration of a refractive lens varies toward compensatory excess because of a temperature rise. On the other hand, the wavelength-shift caused by a temperature change of the semiconductor laser used as a light source is about 0.2 nm/℃. For example, when the temperature rises by 40℃, a wavelength of 8 nm shifts to the long wavelength side.

[0023]

Therefore, if the diffraction lens structure is provided with properties by which spherical aberration varies toward

compensatory deficiency as a result of the shift of a wavelength to the long wavelength side, a change in spherical aberration of the refractive lens that leads to compensatory excess because of a temperature rise can be offset by a change in spherical aberration of the diffraction lens structure that leads to compensatory deficiency as a result of the wavelength-shift to the long wavelength side because of the temperature rise.

[0024]

Although the diffraction lens structure is formed only in the edge region RE of the first surface 11 of the objective lens 10 in the example of Fig. 2, a diffraction lens structure to correct chromatic aberration may be formed in the center region RC when the objective lens 10 is used for both a DVD and a CD. Such a diffraction lens structure may also be formed in the second surface 12 without limiting it to the first surface 11.

Next, four concrete embodiments of the objective lens 10 will be presented on the basis of the above-mentioned mode.

[0025]

[Embodiment 1]

Fig. 3 is a lens drawing that shows an objective lens 10 and a first optical disk D1 according to Embodiment 1. A laser beam strikes the objective lens 10 in the form of parallel rays

of light (object distance ∞), and gathers on the recording surface of the first optical disk D1. A concrete numeric structure of the objective lens 10 of Embodiment 1 is shown in Table 2. The first surface 11 of the objective lens 10 of Embodiment 1 is partitioned into a center region RC in which a height h from an optical axis satisfies $0 \leqq h < 1.50$ and an edge region RE in which the height is expressed as $1.50 \leqq h$. A continuous surface having no level difference is formed in the center region RC, whereas a diffraction lens structure in which spherical aberration is changed depending on wavelengths is formed in the edge region RE. The base curve (i.e., shape that pertains to a refractive lens excluding the diffraction lens structure) of the center region EC and that of the edge region RE are each an independent aspherical surface that is defined by an individual coefficient. The second surface 12 is a rotationally symmetric aspherical surface that has no diffraction lens structure.

[0026]

The shape of the aspherical surface of the center region RC of the first surface 11, the base curve of the edge region of the first surface 11, and the shape of the aspherical surface of the second surface 12 are expressed by the following equation:

$$X(h) = Ch^2 / (1 + \sqrt{(1 - (1 + K)C^2h^2)}) + A_4h^4 + A_6h^6 + A_8h^8 + A_{10}h^{10} + A_{12}h^{12}$$

where X(h) is a distance (amount of sag) from a tangent plane on the optical axis of an aspherical surface of a coordinate point on the aspherical surface in which the height from the optical axis is h, C is curvature (1/r) on the optical axis of the aspherical surface, K is a conical constant, and A_4, A_6, A_8, A_{10}, and A_{12} are 4th, 6th, 8th, 10th, and 12th aspherical coefficients, respectively.

[0027]

The addition amount of an optical path length by the diffraction lens structure can be expressed by an optical path difference function ϕ(h) that is defined by the following equation:

$$\phi(h) = (P2h^2 + P4h^4 + P6h^6 + \cdots) \times m \times \lambda$$

where h is a height from the optical axis, Pn is an n-th optical path difference function coefficient (n: even number), m is a diffraction order, and λ is a wavelength. The optical path difference function ϕ(h) shows an optical path difference between virtual rays that have not been diffracted by the diffraction lens structure and rays that have been diffracted by the diffraction lens structure at the point of the height h from the optical axis on a diffraction surface. In the addition amount, a direction in which an optical path becomes long with respect to an optical path on the axis is defined as positive.

[0028]

A fine shape of an actual diffraction lens structure is determined by deleting a component equal to integral multiples of the wavelength from the optical path length shown by the aforementioned optical path difference function. In more detail, for example, when first-order diffracted light is used, the width of an annular band is determined to allow the optical path difference function to have a difference for one wavelength in the inner periphery and the outer periphery of the annular band, and the level difference between annular bands is determined to give incident light an optical path length difference of one wavelength.

[0029]

Table 2 shows each coefficient that defines the aspherical shape in the center region RC of the first surface 11, each coefficient that defines the base curve and the diffraction lens structure in the edge region RE of the first surface 11, the spacing between the surfaces, the refractive index of line d, Abbe number νd, and each coefficient that defines the aspherical shape of the second surface. In the table, NA_1, f_1, λ_1, WD_1, and OD_1 designate numerical aperture, focal distance of the objective lens (unit: mm), wavelength (unit: nm), operating distance (unit: mm), and object distance (unit: mm),

respectively, that are indicated when the first optical disk D_1 is used.

[0030]

[Table 2]

$NA_1=0.60$ $f_1=3.00$ $\lambda_1=650nm$ $WD_1=1.61$ $OD_1=\infty$

First surface

Center region ($0 \leqq h < 1.50$)

Paraxial curvature radius r 1.870

Aspherical coefficient

κ	-0.500
A4	-2.12×10^{-4}
A6	1.47×10^{-4}
A8	-8.23×10^{-5}
A10	6.09×10^{-5}
A12	-1.92×10^{-5}

Edge region ($1.50 \leqq h$)

Base curve

Paraxial curvature radius r 1.832

Aspherical coefficient

κ	-0.500
A4	-3.44×10^{-3}
A6	7.80×10^{-4}
A8	-7.67×10^{-4}
A10	2.96×10^{-4}
A12	-5.07×10^{-5}

Diffraction lens structure

Optical path difference function coefficient

P_2	4.61
P_4	-2.12
P_6	0.00
P_8	0.00
P_{10}	0.00
P_{12}	0.00

Spacing between first and second surfaces	d	1.80
Lens refractive index	nd	1.5436
Lens Abbe number	νd	55.7
Disk refractive index	nd	1.5855
Disk Abbe number	νd	29.9

Second surface

Paraxial curvature radius r -8.109

Aspherical coefficient

κ	0.00
A4	1.68×10^{-2}
A6	-2.57×10^{-3}
A8	2.20×10^{-4}
A10	-1.68×10^{-4}
A12	2.93×10^{-5}

[0031]

(A) of Fig. 4 shows spherical aberration SA and a sine condition SC at a wavelength of 650 nm with respect to the first optical disk D1 of the objective lens 10 of Embodiment 1, and (B) of Fig. 4 shows chromatic aberration indicated by spherical aberration at wavelengths of 650 nm, 645 nm, and 655 nm. In the graphs of (A) and (B), the horizontal axis shows the aberration generation amount (unit: mm), and the vertical axis shows a numerical aperture NA.

[0032]

(A) and (B) of Fig. 5 show aberration, as in (A) and (B) of Fig. 4, in a case in which the refractive index of the resin of the lens lowers by 0.0044. This change in the refractive index corresponds to a change in a case in which the temperature rises by 40℃. When the refractive index lowers because of a

temperature rise, spherical aberration SA varies toward the "over" side as NA becomes greater as shown in (A) of Fig. 5, but it temporarily returns to the "under" side on the borderline between the center region RC and the edge region RE, and therefore the generation of spherical aberration in a high NA region can be consequentially stopped. If a diffraction lens structure is not provided, spherical aberration monotonously varies toward the "over" side as NA becomes greater, and the amount of spherical aberration generated in the high NA region becomes superfluous.

[0033]

[Embodiment 2]

Table 3 shows a concrete numeric structure of an objective lens of Embodiment 2. The objective lens of Embodiment 2 is the same as the objective lens of Embodiment 1 in basic shape, and is different therefrom only in the structure in the edge region RE of the first surface. Therefore, only the numerical values in this region are shown. Additionally, its lens drawing is omitted because its exterior is the same as in Fig. 3.

[0034]

[Table 3]

First surface
Edge region ($1.50 \leqq h$)

Base curve

Paraxial curvature radius r 1.870

Aspherical coefficient

κ	-0.500
A4	2.36×10^{-3}
A6	-5.50×10^{-4}
A8	-5.23×10^{-4}
A10	2.12×10^{-4}
A12	-4.20×10^{-5}

Diffraction lens structure

Optical path difference function coefficient

P_2	0.00
P_4	2.25
P_6	-1.03
P_8	0.00
P_{10}	0.00
P_{12}	0.00

[0035]

(A) of Fig. 6 shows spherical aberration SA and a sine condition SC at a wavelength of 650 nm with respect to the first optical disk D1 of the objective lens of Embodiment 2, and (B) of Fig. 6 shows chromatic aberration indicated by spherical aberration at wavelengths of 650 nm, 645 nm, and 655 nm. (A) and (B) of Fig. 7 show aberration, as in (A) and (B) of Fig. 6, in a case in which the refractive index of the resin of the lens lowers

by 0.0044. When the refractive index lowers because of a temperature rise, spherical aberration SA varies toward the "over" side in a low NA region as NA becomes greater as shown in (A) of Fig. 7, but it temporarily returns to the "under" side on the borderline between the center region RC and the edge region RE, and it returns to the "under" side in a high NA region as NA becomes greater, and therefore the generation of spherical aberration in the high NA region can be consequentially stopped.

[0036]

[Embodiment 3]

Fig. 8 is a lens drawing that shows an objective lens 10 and a first optical disk D1 according to Embodiment 3. A concrete numeric structure of the objective lens 10 of Embodiment 3 is shown in Table 4. A first surface 21 of the objective lens 10 of Embodiment 3 is partitioned into a center region RC in which a height h from an optical axis satisfies $0 \leqq h < 1.50$ and an edge region RE in which the height is expressed as $1.50 \leqq h$. A diffraction lens structure for chromatic aberration correction is formed in the center region RC, whereas a diffraction lens structure for temperature compensation is formed in the edge region RE. A second surface 22 is a rotationally symmetric aspherical surface that has no

diffraction lens structure.

[0037]

[Table 4]

$NA_1=0.60$ $f_1=3.00$ $\lambda_1=650nm$ $WD_1=1.63$ $OD_1=\infty$

First surface

Center region ($0\leqq h<1.50$)

Base curve

Paraxial curvature radius r 1.935

Aspherical coefficient

κ	-0.500
A4	-5.14×10^{-4}
A6	6.75×10^{-4}
A8	-1.36×10^{-4}
A10	4.17×10^{-5}
A12	-2.00×10^{-5}

Diffraction lens structure

Optical path difference function coefficient

P_2	-2.00
P_4	-1.54
P_6	3.70×10^{-1}
P_8	0.00
P_{10}	0.00
P_{12}	0.00

Edge region ($1.50 \leqq h$)

Base curve

Paraxial curvature radius r 1.926

Aspherical coefficient

κ	-0.500
A4	7.55×10^{-4}
A6	3.00×10^{-6}
A8	-3.27×10^{-4}
A10	8.90×10^{-5}
A12	-2.68×10^{-5}

Diffraction lens structure

Optical path difference function coefficient

P_2	-9.97×10^{-1}
P_4	-3.60×10^{-1}
P_6	-4.00×10^{-1}
P_8	0.00
P_{10}	0.00
P_{12}	0.00

Spacing between first and second surfaces	d	1.80
Lens refractive index	nd	1.5436
Lens Abbe number	νd	55.7
Disk refractive index	nd	1.5855
Disk Abbe number	νd	29.9

Second surface

Paraxial curvature radius r -7.075

Aspherical coefficient

κ	0.00
A4	2.61×10^{-2}
A6	-7.19×10^{-3}
A8	4.83×10^{-4}
A10	7.91×10^{-5}
A12	-1.50×10^{-5}

[0038]

(A) of Fig. 9 shows spherical aberration SA and a sine condition SC at a wavelength of 650 nm with respect to the first optical disk D1 of the objective lens of Embodiment 3, and (B) of Fig. 9 shows chromatic aberration indicated by spherical aberration at wavelengths of 650 nm, 645 nm, and 655 nm. (A) and (B) of Fig. 10 show aberration, as in (A) and (B) of Fig. 9, in a case in which the refractive index of the resin of the lens lowers by 0.0044. When the refractive index lowers because of a temperature rise, spherical aberration SA varies toward the "over" side in a low NA region as NA becomes greater as shown in (A) of Fig. 10, but it temporarily returns to the "under" side on the borderline between the center region RC and the edge region RE, and it returns to the "under" side in a high NA region as NA becomes greater, and therefore the generation

of spherical aberration in the high NA region can be consequentially stopped.

[0039]

[Embodiment 4]

Fig. 11 is a lens drawing that shows an objective lens 10 and a first optical disk D1 according to Embodiment 4. A concrete numeric structure of the objective lens 10 of Embodiment 4 is shown in Table 5. A first surface 11 of the objective lens 10 of Embodiment 4 is a rotationally symmetric aspherical surface that has no diffraction lens structure. A second surface 12 thereof is partitioned into a center region RC in which a height h from an optical axis satisfies $0 \leqq h < 1.20$ and an edge region RE in which the height is expressed as $1.20 \leqq h$. A continuous surface having no level difference is formed in the center region RC, and a diffraction lens structure in which spherical aberration is changed depending on wavelengths is formed in the edge region RE.

[0040]

[Table 5]

$NA_1=0.60$ $f_1=3.00$ $\lambda_1=650nm$ $WD_1=1.61$ $OD_1=\infty$

First surface

Paraxial curvature radius r 1.882

Aspherical coefficient

κ -0.50

A4	-3.53×10^{-4}
A6	2.62×10^{-5}
A8	-1.04×10^{-4}
A10	3.05×10^{-5}
A12	-1.56×10^{-5}

Spacing between first and second surfaces	d	1.80
Lens refractive index	nd	1.5436
Lens Abbe number	νd	55.7
Disk refractive index	nd	1.5855
Disk Abbe number	νd	29.9

Second surface

Center region ($0 \leqq h < 1.20$)

Paraxial curvature radius r -7.816

Aspherical coefficient

κ	0.00
A4	1.66×10^{-2}
A6	-3.35×10^{-3}
A8	-1.18×10^{-4}
A10	1.48×10^{-4}
A12	-2.83×10^{-5}

Edge region ($1.20 \leqq h$)

Base curve

Paraxial curvature radius r -7.439

Aspherical coefficient

κ	-0.500
A4	1.76×10^{-2}
A6	-1.94×10^{-3}

A8	-2.73×10^{-4}
A10	1.50×10^{-4}
A12	-1.69×10^{-5}

Diffraction lens structure

Optical path difference function coefficient

P_2	2.70
P_4	-5.00×10^{-1}
P_6	-1.23
P_8	0.00
P_{10}	0.00
P_{12}	0.00

[0041]

(A) of Fig. 12 shows spherical aberration SA and a sine condition SC at a wavelength of 650 nm with respect to the first optical disk D1 of the objective lens of Embodiment 4, and (B) of Fig. 12 shows chromatic aberration indicated by spherical aberration at wavelengths of 650 nm, 645 nm, and 655 nm. (A) and (B) of Fig. 13 show aberration, as in (A) and (B) of Fig. 12, in a case in which the refractive index of the resin of the lens lowers by 0.0044. When the refractive index lowers because of a temperature rise, spherical aberration SA varies toward the "over" side in a low NA region as NA becomes greater as shown in (A) of Fig. 12, but it temporarily returns to the "under" side on the borderline between the center region RC and the edge region RE, and it returns to the "under" side in

a high NA region as NA becomes greater, and therefore the generation of spherical aberration in the high NA region can be consequentially stopped.

[0042]

Table 6 shows a change in wave front aberration (rms, unit: λ) in correlation with a temperature change ΔT℃ of the objective lens, and gives values of the objective lenses of the above-mentioned four embodiments and values of an objective lens of a comparative example in which a diffraction lens structure is not provided. Fig. 14 is a graph of Table 6.

[0043]

[Table 6]

ΔT (℃)	Wave front aberration				
	Embodiment 1	Embodiment 2	Embodiment 3	Embodiment 4	Comparative example
0	0.002	0.001	0.001	0.002	0.000
10	0.007	0.006	0.005	0.005	0.011
20	0.011	0.009	0.009	0.011	0.022
30	0.016	0.014	0.012	0.015	0.033
40	0.020	0.018	0.016	0.020	0.043

[0044]

As shown in Table 6 and in Fig. 14, the formation of the diffraction lens structure in the edge region RE makes it possible to keep the generation amount of wave front aberration caused by a temperature change less than half of that in the case in which the diffraction lens structure is not formed there.

Accordingly, if a diffraction lens structure for temperature compensation is formed only in the edge region RE as in the above examples, the generation of wave front aberration can be kept small, and an objective lens applicable to a situation in which the center region is compatibly used for optical disks different in standards from each other can be constructed.

[0045]

In other words, if the diffraction lens structure for temperature compensation is further formed in the center region RC, a deterioration in wave front aberration caused by a temperature change can be reduced to be small with respect to the first optical disk, such as a DVD, but the increase in wavelength dependence makes it impossible to apply the objective lens to other optical disks in which a wavelength to be used is different from that of the first optical disk. In contrast, if the diffraction lens structure for temperature compensation is formed only in the edge region, the edge region serves as an exclusive region suitable for use of the first optical disk, and the objective lens can also be applied to other optical disks in which a different wavelength is used for the center region.

[0046]

Especially in a case in which an optical disk, such as a

CD, (hereinafter referred to as a "second optical disk") that has a relatively low recording density and has a thick protective layer is used by the use of a laser beam of a long wavelength, a light beam that has passed through the edge region is diffused, so that a beam spot formed by substantially reducing the NA can be prevented from unnecessarily becoming small if the edge region is used as an exclusive region for the first optical disk, as described above, when the second optical disk is used.

[0047]

Referring now to Fig. 15, a description will be provided of a second mode in which the objective lenses of the above-mentioned four embodiments are applied to an optical head capable of using two kinds of optical disks. Fig. 15 is an explanatory drawing for explaining an optical system of the optical head by which recording or reproducing can be carried out onto or from a DVD having a high recording density and a CD and a CD-R (CD-recordable), each having a low recording density. This optical system is made up of a first laser module 21, a second laser module 22, a beam combiner 23, a collimating lens 24, and an objective lens 10. Each of the modules 21 and 22 is an element in which a semiconductor laser and a sensor are integrated with each other.

[0048]

Like the laser module of Fig. 1, the first laser module 21 includes a semiconductor laser whose oscillation wavelength is 650 nm. On the other hand, in order to use at least the CD-R of the second optical disks D2 each of which has a low recording density and has a protective layer of 1.2 mm, near infrared light is needed because of its spectral reflectance. Therefore, the second laser module 22 includes a semiconductor laser whose oscillation wavelength is 780 nm.

[0049]

When the first optical disk D1 (indicated by the solid line in the figure) is used, the first laser module 21 is actuated. The objective lens 10 is disposed at a position indicated by the solid line in the figure. A first laser beam having a wavelength of 650 nm that has been emitted from the semiconductor laser of the first laser module 21 strikes the objective lens 10 in the form of parallel rays of light, is then condensed by the objective lens 10, and forms a beam spot on the recording surface of the first optical disk D1, as indicated by the solid line in the figure. On the other hand, when the second optical disk D2 (indicated by the broken line in the figure) is used, the second laser module 22 is actuated. The objective lens 10 is disposed at a position closer to the optical disk as indicated by the broken line in the figure. A second laser

beam having a wavelength of 780 nm that has been emitted from the semiconductor laser of the second laser module 22 strikes the objective lens 10 in the form of divergent light, is then condensed by the objective lens 10, and forms a beam spot on the recording surface of the second optical disk D2, as indicated by the broken line in the figure.

[0050]

The diffraction lens structure formed in the edge region RE of the objective lens 10 prevents a deterioration in wave front aberration caused by a temperature change when the first laser beam is gathered on the first optical disk, whereas spherical aberration is generated when the second laser beam is gathered on the second optical disk. Therefore, when the first optical disk D1 is used, the first laser beam that has entered the center region RC and the edge region RE is gathered at the same position, and the NA becomes relatively large, and thus the spot diameter can be reduced to be small, and a deterioration in light-gathering performance caused by a temperature change can be prevented. On the other hand, when the second optical disk D2 is used, the second laser beam that has entered the edge region RE is diffused, and only the laser beam that has entered the center region RC forms a beam spot, and thus the NA substantially becomes small, and the spot

diameter becomes greater than that of the first laser beam. Since the NA is small when the second optical disk is used, the deterioration in wave front aberration caused by a temperature change is negligible.

[0051]

If the laser beam with a wavelength of 780 nm that has been emitted from the second laser module 22 is caused to enter in the form of divergent light so that the object distance of the objective lens 10 becomes -52.0 mm when the objective lenses of Embodiments 1 through 4 are applied to the optical system of Fig. 15, an excellent beam spot can be formed on the second optical disk.

[0052]

[Effects of the Invention]

As described above, according to the present invention, if a diffraction lens structure that can prevent a change in light-gathering performance caused by a temperature change is formed in an edge region of an objective lens, it is possible to prevent a deterioration in wave front aberration caused by the temperature change and enlarge a temperature range in which an apparatus can be used even in the case of an objective lens, such as that of a DVD, in which a high NA is required. Further, if a diffraction lens structure for temperature compensation

is formed only in an edge region, a center region can be designed as a compatible region in a situation where another optical disk, such as a CD, different in a required NA and different in standards is used, and therefore it is possible to simplify the structure of its optical system and make it smaller in size and in cost than a case where exclusive objective lenses are provided for individual optical disks.

[BRIEF DESCRIPTION OF THE DRAWINGS]

[Fig. 1]

Explanatory drawing of an optical system of an optical head according to a first embodiment.

[Fig. 2]

(A) front view, (B) longitudinal sectional view, and (C) partially enlarged view of the longitudinal section of an objective lens used for the optical system of Fig. 1.

[Fig. 3]

Lens drawing that shows an objective lens for the optical head of Embodiment 1 and an optical disk.

[Fig. 4]

(A) graph of spherical aberration and (B) graph of chromatic aberration when a first optical disk of the objective lens of Embodiment 1 is used.

[Fig. 5]

(A) graph of spherical aberration and (B) graph of chromatic aberration when the first optical disk is used in a case where the refractive index of the objective lens of Embodiment 1 lowers by 0.0044.

[Fig. 6]

(A) graph of spherical aberration and (B) graph of chromatic aberration when the first optical disk of an objective lens of Embodiment 2 is used.

[Fig. 7]

(A) graph of spherical aberration and (B) graph of chromatic aberration when the first optical disk is used in a case where the refractive index of the objective lens of Embodiment 2 lowers by 0.0044.

[Fig. 8]

Lens drawing that shows an objective lens for an optical head of Embodiment 3 and an optical disk.

[Fig. 9]

(A) graph of spherical aberration and (B) graph of chromatic aberration when a first optical disk of the objective lens of Embodiment 3 is used.

[Fig. 10]

(A) graph of spherical aberration and (B) graph of chromatic aberration when the first optical disk is used in a case where

the refractive index of the objective lens of Embodiment 3 lowers by 0.0044.

[Fig. 11]

Lens drawing that shows an objective lens for an optical head of Embodiment 4 and an optical disk.

[Fig. 12]

(A) graph of spherical aberration and (B) graph of chromatic aberration when the first optical disk of the objective lens of Embodiment 4 is used.

[Fig. 13]

(A) graph of spherical aberration and (B) graph of chromatic aberration when the first optical disk is used in a case where the refractive index of the objective lens of Embodiment 4 lowers by 0.0044.

[Fig. 14]

Graph that shows a change in wave front aberration in correlation with a temperature change of the objective lenses of the embodiments and a comparative example.

[Fig. 15]

Explanatory drawing of an optical system of an optical head according to a second mode.

[Fig. 16]

Graph that shows a variation in wave front aberration (unit:

λ (wavelength)) when the temperature rises by 40 degrees of a resinous lens whose focal distance is 3.0 mm and wavelength in use is 650 nm, in which NA is used as a parameter.

[Description of Symbols]

10 Objective lens

11 First surface

12 Second surface

D1 First optical disk

21 Laser module

24 Collimating lens

[TITLE OF DOCUMENT] Abstract

[ABSTRACT]

[OBJECT] It is an object to control a change in wave front aberration caused by a temperature change so as to be small and enlarge a usable temperature range when used as a high NA objective lens.

[COMPOSITION] An optical system of an optical head is made up of a laser module 21, a collimating lens 24, and an objective lens 10. The laser module 21 is an element in which a semiconductor laser and a sensor are integrated with each other, and is disposed so that a first laser beam emitted from the collimating lens 24 strikes the objective lens 10 in the form of parallel rays of light. A first surface 11 of the objective lens 10 is partitioned into a center region and an edge region enclosing the perimeter of the center region. The edge region RE is divided so as to become narrower than the center region RC. A diffraction lens structure formed in the edge region RE functions to compensate a change in light-gathering properties caused by a temperature change.

[SELECTIVE DRAWING] Fig. 2

Fig.1

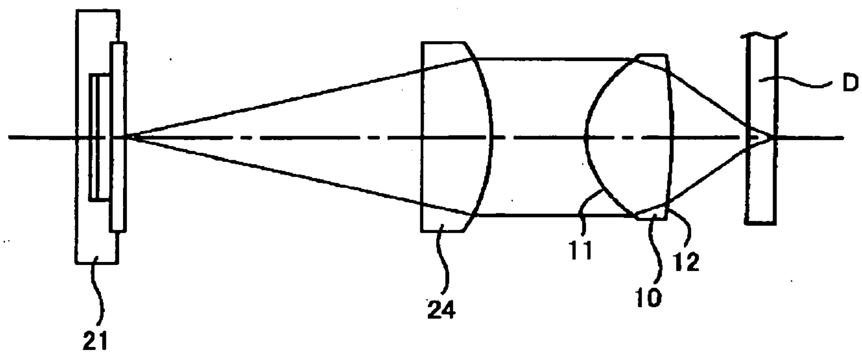


Fig.2

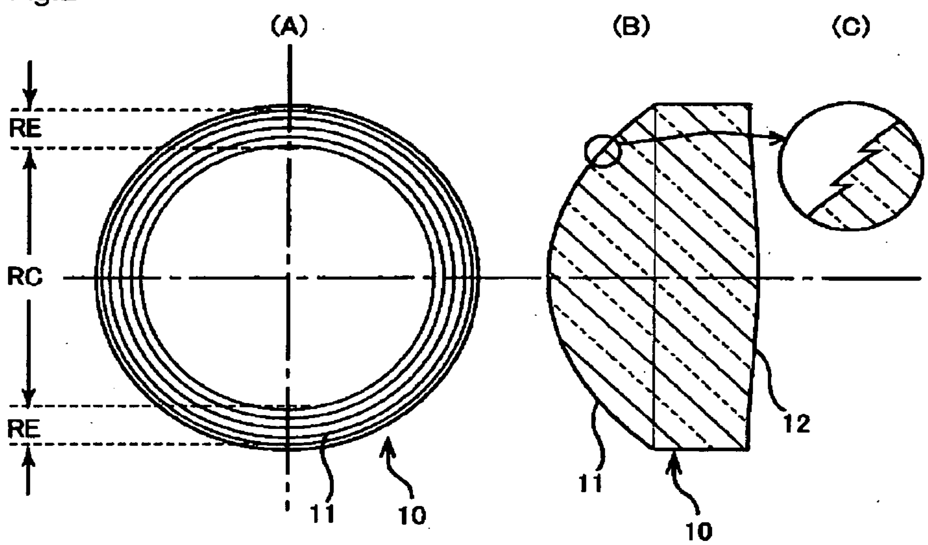
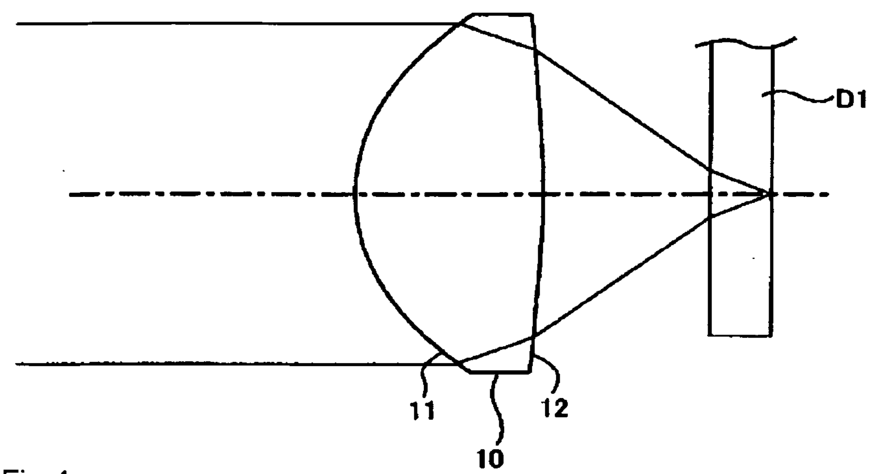
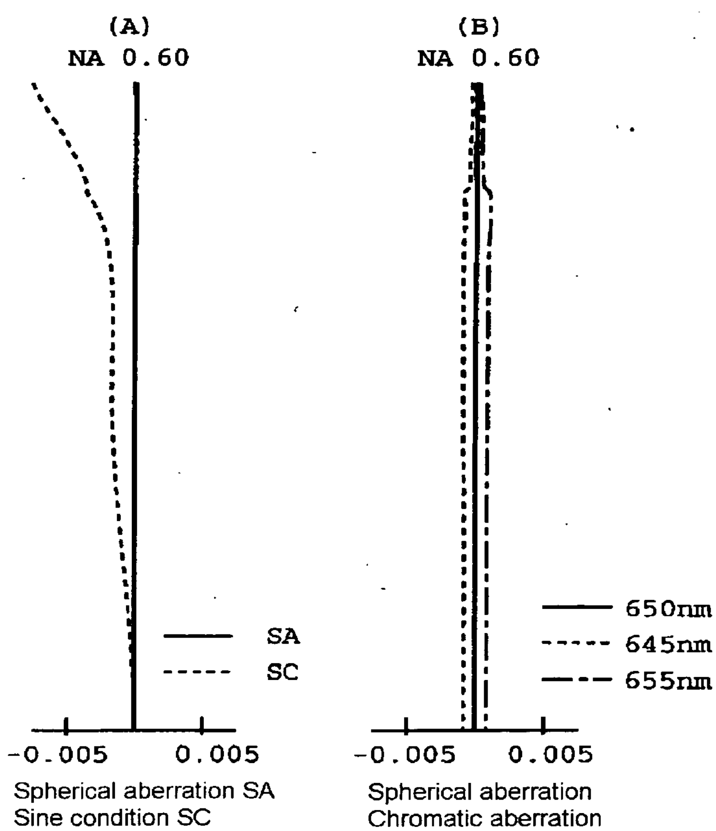


Fig.3



D1
11
12
10

Fig.4



(A)
NA 0.60
SA
SC
-0.005
0.005
Spherical aberration SA
Sine condition SC
(B)
NA 0.60
650nm
645nm
655nm
-0.005
0.005
Spherical aberration
Chromatic aberration

Fig.5

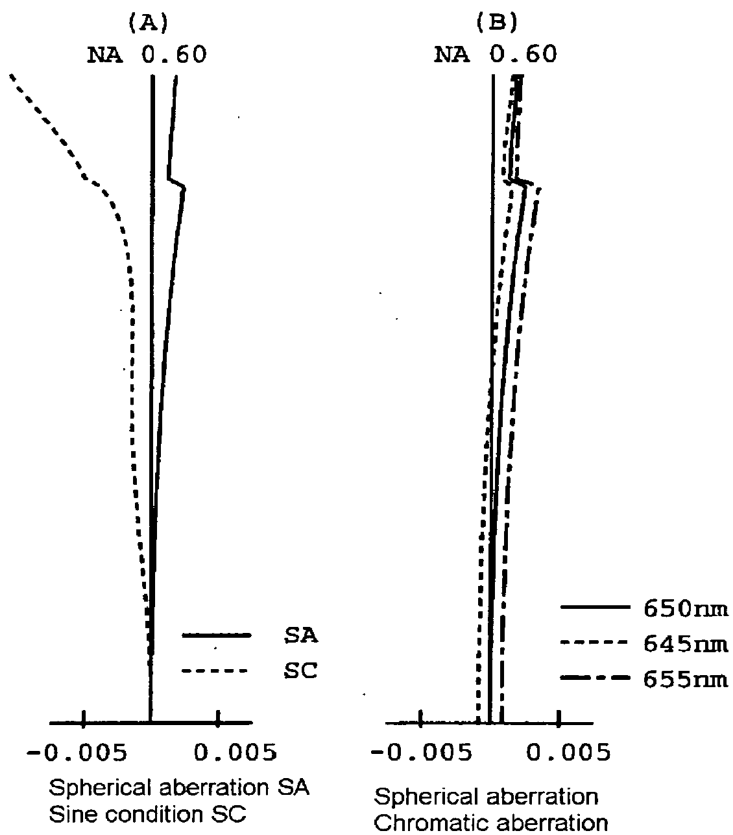

(A)
NA 0.60
SA
SC
-0.005
0.005
Spherical aberration SA
Sine condition SC
(B)
NA 0.60
650nm
645nm
655nm
-0.005
0.005
Spherical aberration
Chromatic aberration

Fig.6

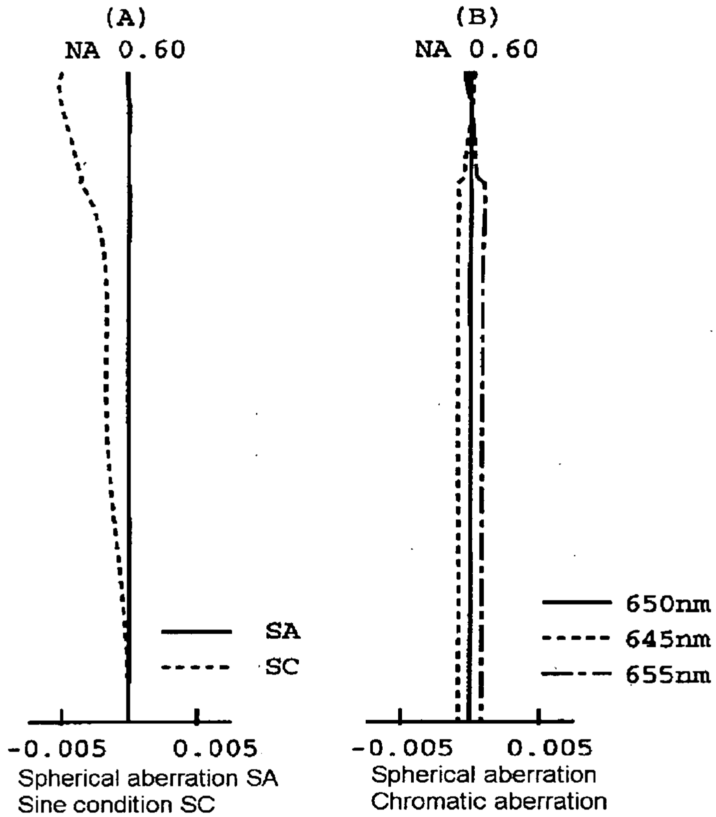

(A)
NA 0.60
SA
SC
-0.005
0.005
Spherical aberration SA
Sine condition SC
(B)
NA 0.60
650nm
645nm
655nm
-0.005
0.005
Spherical aberration
Chromatic aberration

Fig.7

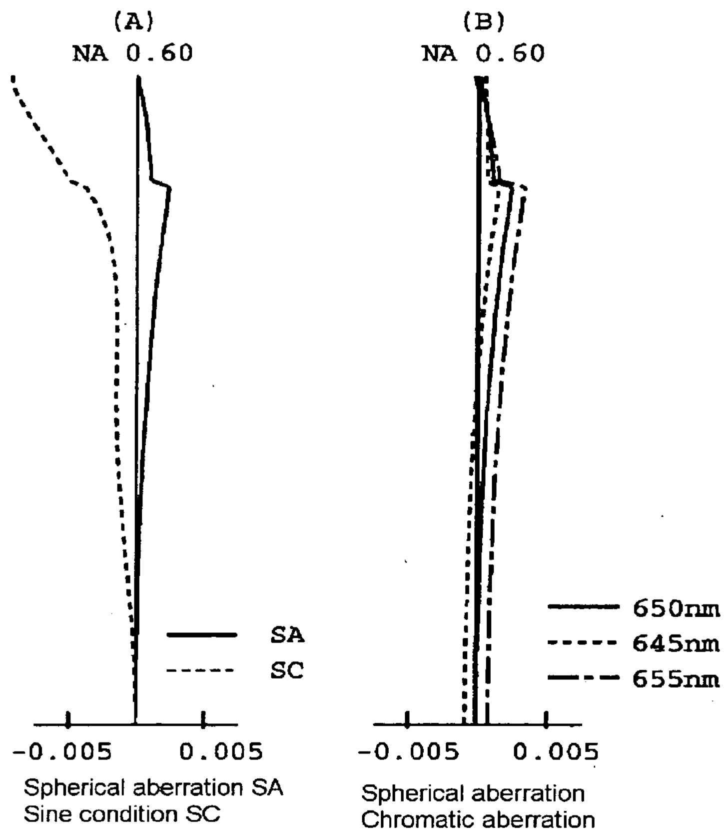

(A)
NA 0.60
SA
SC
-0.005
0.005
Spherical aberration SA
Sine condition SC
(B)
NA 0.60
650nm
645nm
655nm
-0.005
0.005
Spherical aberration
Chromatic aberration

Fig.8

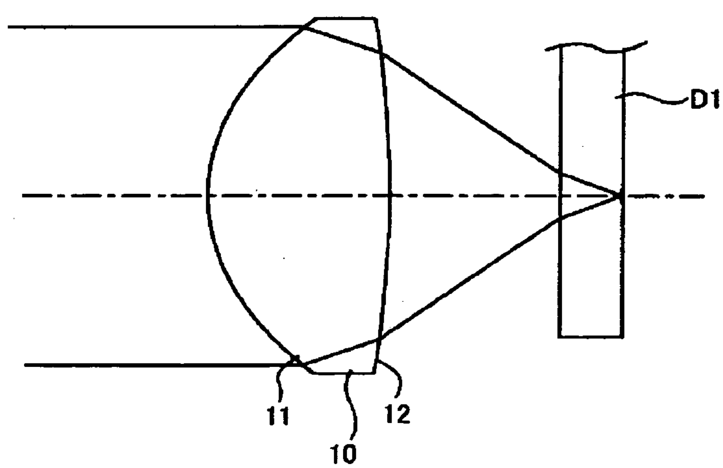
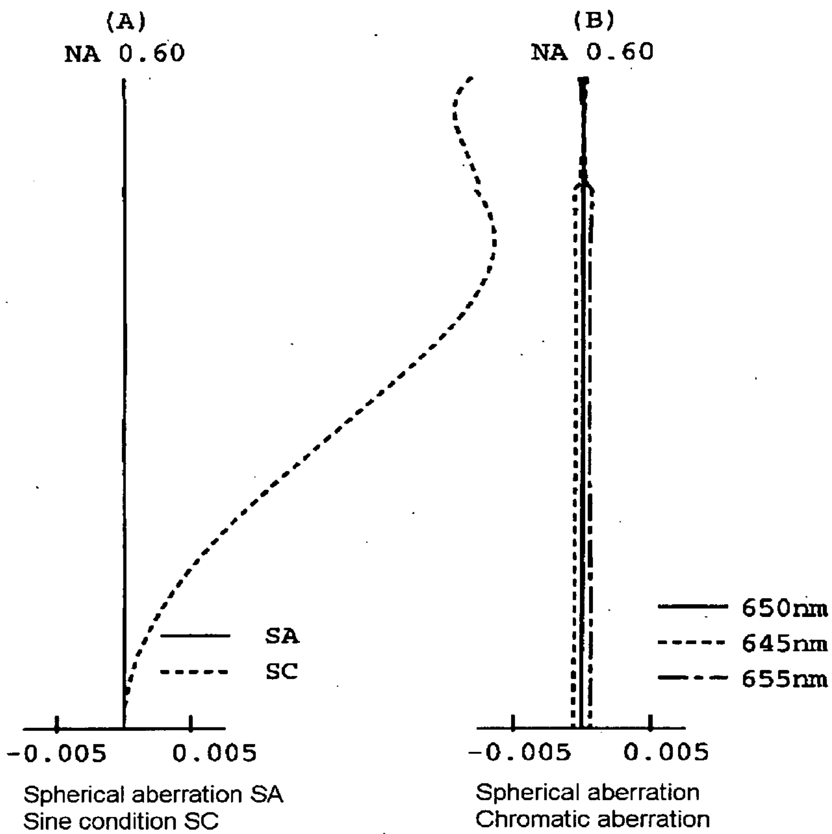

D1
11
12
10

Fig.9



(A)
NA 0.60
SA
SC
-0.005
0.005
Spherical aberration SA
Sine condition SC
(B)
NA 0.60
650nm
645nm
655nm
-0.005
0.005
Spherical aberration
Chromatic aberration

Fig.10

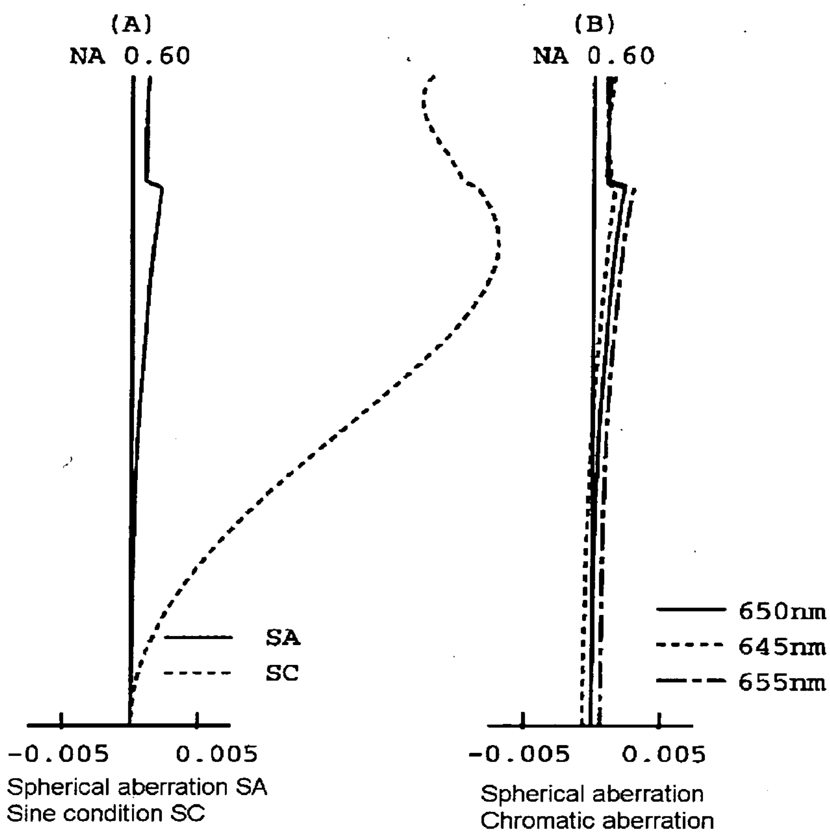

(A)
NA 0.60
SA
SC
-0.005
0.005
Spherical aberration SA
Sine condition SC
(B)
NA 0.60
650nm
645nm
655nm
-0.005
0.005
Spherical aberration
Chromatic aberration

Fig.11

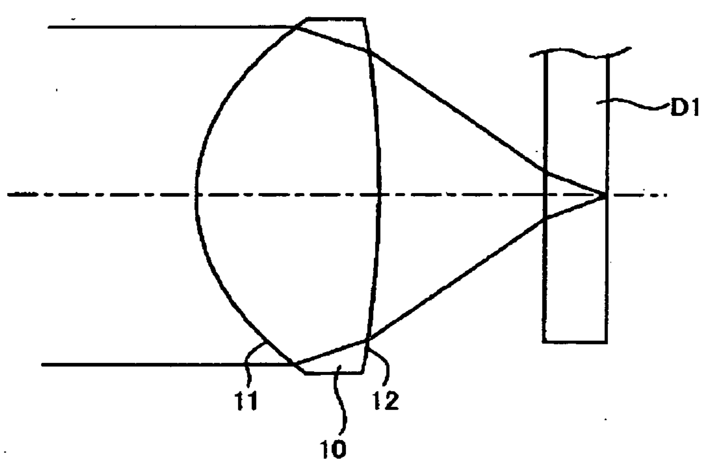
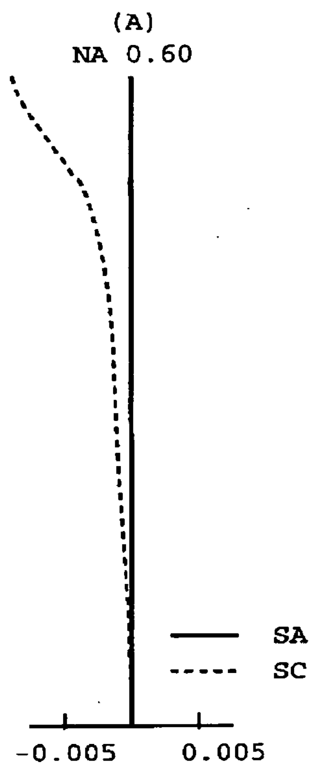
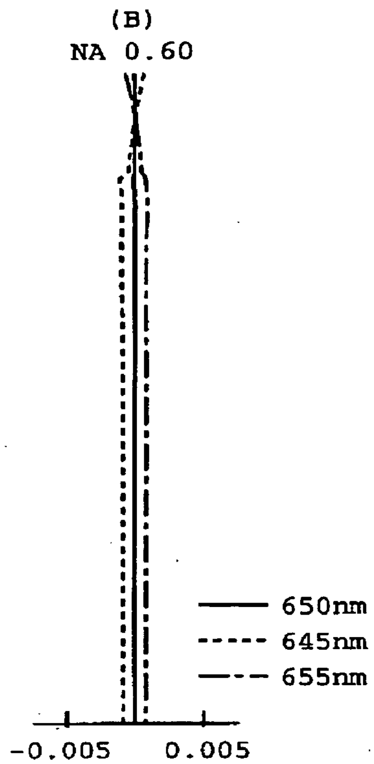

D1
11
12
10

Fig.12



Spherical aberration SA
Sine condition SC



Spherical aberration
Chromatic aberration

Fig.13

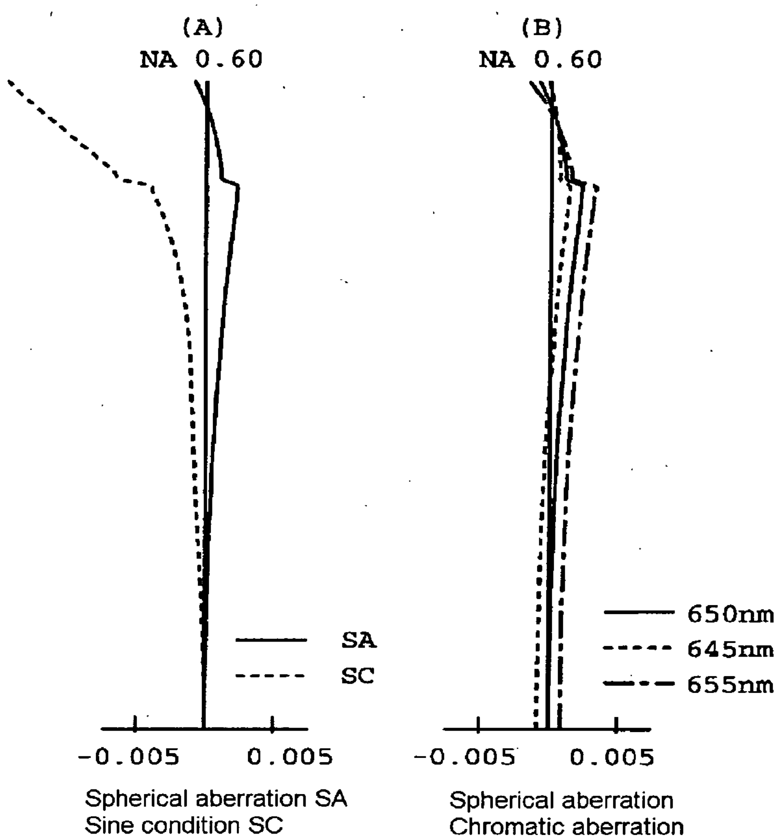
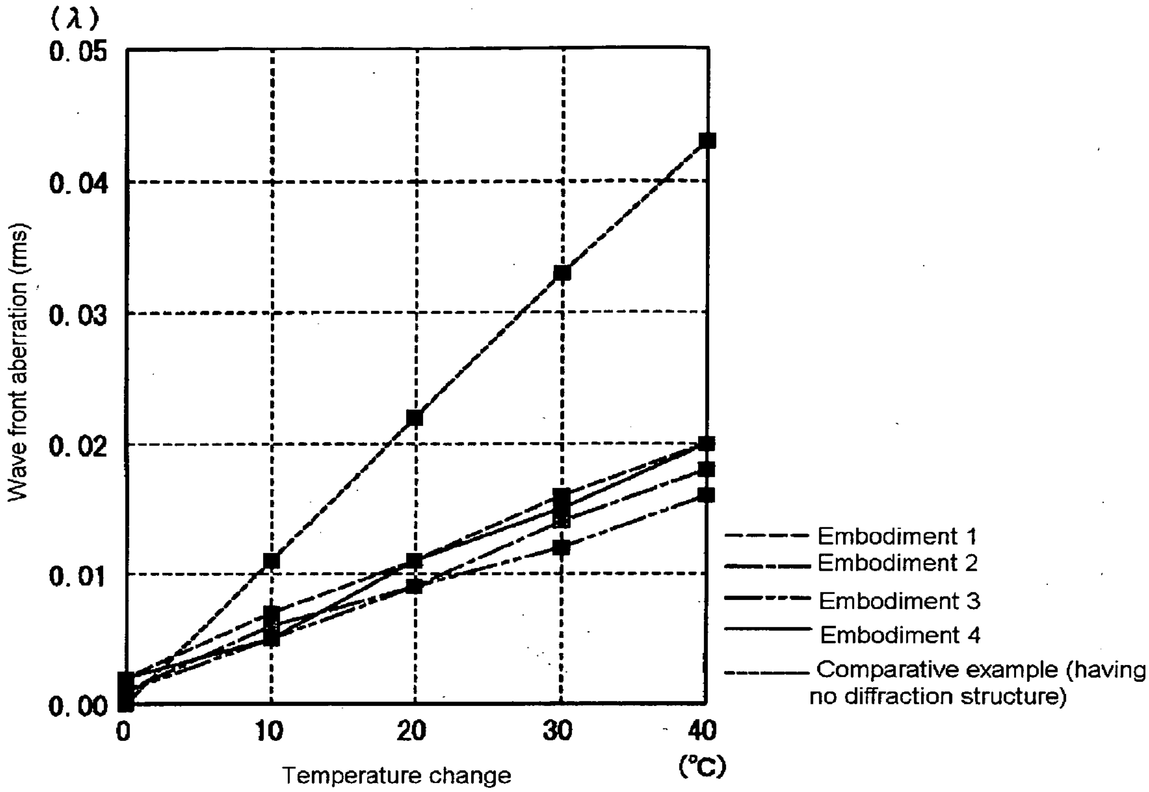
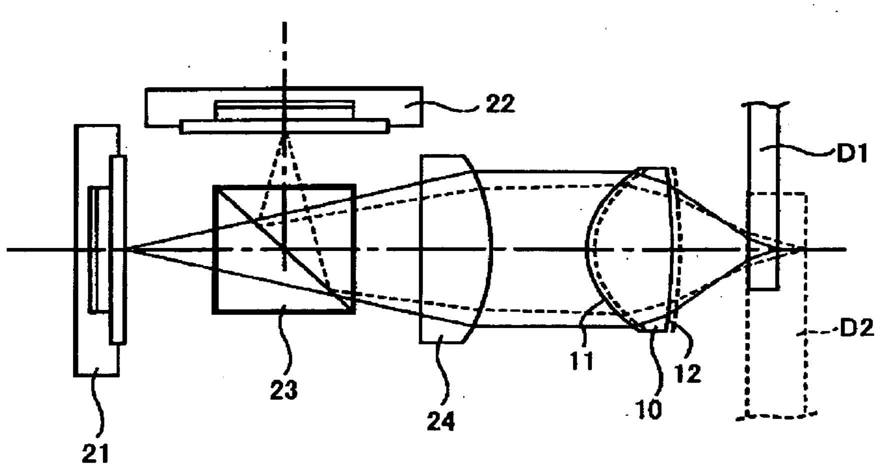

(A)
NA 0.60
SA
SC
-0.005
0.005
Spherical aberration SA
Sine condition SC
(B)
NA 0.60
650nm
645nm
655nm
-0.005
0.005
Spherical aberration
Chromatic aberration

Fig.14



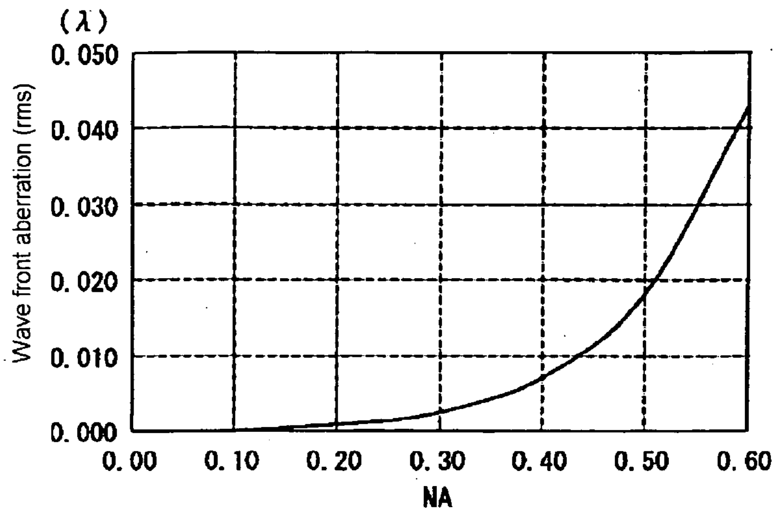
(λ)
0.05
0.04
0.03
0.02
0.01
0.00
Wave front aberration (rms)
0
10
20
30
40
(°C)
Temperature change
Embodiment 1
Embodiment 2
Embodiment 3
Embodiment 4
Comparative example (having no diffraction structure)

Fig.15



22
D1
D2
21
23
24
11
10
12

Fig.16



(λ)
0.050
0.040
0.030
0.020
0.010
0.000
Wave front aberration (rms)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
NA